# Pressure Variation with Temperature Change
# PADI IDC Method vs. Ideal Gas Law

Following article is about how to calculate the pressure variation in a SCUBA cylinder when the temperature of the cylinder changes: the method given in PADI Instructor Development Courses (IDCs) provides slightly different results than the calculations derived from the Ideal Gas Law. This article intends to demonstrate how the PADI Approximation and the Ideal Gas Law are related, and why the two methods are almost equivalent.

## PROBLEM

Following discussion is about how to calculate the pressure variation in a SCUBA cylinder when the temperature of the cylinder changes.

* In IDC exams, PADI tells students to base calculations on a 0.6 bar increase or decrease in pressure for each 1°C variation of the temperature of the tank. In other words: **delta P = 0.6 x delta T**

* The Ideal Gas Law, on the other hand, states that PV=nR.T. Since n.R is constant, and the volume of the tank is a constant as well, it means that P1/T1=P2/T2, or, in other words, that:
P2=P1xT1/T2, or **delta P = P1- P1xT1/T2**

Depending on whether we use the PADI approximation (delta P = 0.6 x delta T ) or the Ideal Gas Law (delta P = P1- P1xT1/T2), we'll find slightly different results for the pressure change resulting from temperature change in a tank.

This article intends to demonstrate how the PADI Approximation and the Ideal Gas Law are related, and why the two methods are almost equivalent.

## DEMONSTRATION

### 1. Ideal Gas Law

The Ideal Gas Law states that P.V = n.R.T, where
- P is the absolute pressure, in bars or atm
- V is the volume, in liters
- n is the amount of moles of gas (knowing that the number of atoms or molecules in one mole of a substance is equal to Avogadro's constant, or 6.023 × $10^{23}$)
- R is the Gas Constant, in L.atm.$K^{-1}$.$mol^{-1}$
- T is the absolute temperature, in °K (knowing that °K = °C + 273)

The number of molecules of gas does not change in a cylinder when I increase its temperature (n is constant) - and the Gas constant is, by definition, a constant.

If PV=nRT, it therefore means that P2-P1=nR.T2/V-nR.T1/V, which is equivalent to:

**delta P = nR/V x (T2-T1) (1)**

This looks more like the PADI approximation - but we need to calculate the numerical value for nR/V.

### 2. Quantity of gas in a cylinder (i.e. amount of moles) and Standard Molar Volume

The trick for doing so is that the amount of moles in the cylinder will naturally depend on the pressure - and hence, when considering a scuba cylinder with a fixed volume, on the pressure inside that cylinder.

Let's just assume that we usually work with full AL80 cylinders, i.e. 200 bars in a 11.1 liters cylinder, which is to say an uncompressed volume of 11.1 x 200 = 2220 L

You probably remember from your school days that the Standard Molar Volume is 22.414 L/mol, which means that for any given gas, 1 mol of this gas will take 22.4 liters at 1atm - but this is only valid at Standard Temperature and Pressure, which is to say at 0°C, or 273°K. The amount of molecules, i.e. moles of molecules in the cylinder is however determined when the cylinder is filled. Due to the heat of compression, the temperature inside a cylinder during the filling process can easily reach around 40°C, or 40+273 = 333°K. We therefore need to know what the Standard Molar Volume (SMV) would be at a temperature of 313°K.

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Charle's law states that the volume of a given mass of gas is directly proportional to its temperature on the absolute scale when the pressure is held constant. In other words: V1/T1=V2/T2 if the pressure is constant.

Knowing that the volume of gas is given by: V=SMV x n, where n, the number of moles of gas, is constant if I don't change the quantity of gas in my cylinder, and SMV the Standard Molar volume, it follows that: SMV1/T1=SMV2/T2

The Standard Mass volume at a given temperature t in ºK (SMVt) will therefore be:

**SMVt = (22.414 x t ) / 273 (2)**

Using equation (2), I can therefore calculate SMV313=22.414 x 313 / 273 = 25.55 L/mol

At a filling temperature of 60ºC, or 333ºK, each mole of gas will occupy a 25.55 L at a pressure of 1atm (approx. 1 bar). The amount of moles in my cylinder can thus be calculated as follows:

n = V / SMV = 2220 / 25.55 = 86.4 mol

I therefore have approximately 86.4 moles of gas in a standard AL80 scuba cylinder filled up to 200 bar at an inside filling temperature of 60ºC.

As for the Gas Constant, we need to express it in $L.atm.K^{-1}.mol^{-1}$, and not in the usual $J.K^{-1}.mol^{-1}$ sometimes used in physics text books, since we work with volumes in liters and pressures in bars or atm. I'll use R = 0.082057338 $L.atm.K^{-1}.mol^{-1}$.

### 3. Calculation of the pressure variation ratio for temperature changes

Now that we have the 3 numerical values for the number of moles of gas in the cylinder (n), the Gas Constant (R) and the volume of the cylinder (V), we can calculate the value of n.R/V:

n.R/V = 86.4*0.082057338/11.88 = 0.597, or approximately 0.6.

If we insert this value into equation (1), we obtain:

**delta P = 0.6 x (T2-T1)**

Which is the PADI approximation method - and looks like magic.

## CONCLUSION

Both methods are equivalent, and based on the same physical laws: the Ideal Gas Law, Charle's law, the relationship between volume and the quantity of gas, etc.

The method based on the Ideal Gas law tends to be more accurate, as it does not depend on the volume of the cylinder or the filling temperature, while the PADI method offers an approximation based on a standard size of cylinder (11.88L), and a standard filling temperature (60ºC). The advantage of the PADI method is that it makes the calculation slightly simpler, since it does not require the student to understand or remember the Ideal Gas Law, and gives an approximation which can easily be applied in the field.

What you use is up to you, as both methods are somewhat equivalent. I tend to use the Ideal Gas Law method (delta P = P1- P1xT1/T2), as it seems very logical to me - but if your only goal is to pass the IDC theory exam, and hence to find a value that matches a Multiple Choice Answer, then you should definitely use the PADI approximation (delta P = 0.6 x delta T).


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